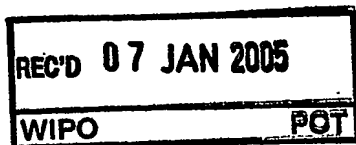




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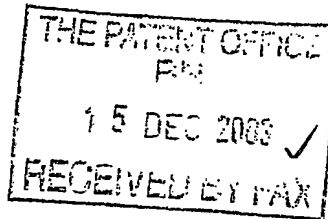
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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*  
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- Patents ADP Number *(if you know it)*
- If the applicant is a corporate body, give the country/state of its incorporation **THE NETHERLANDS ✓**
4. Title of the invention **PHOTO SENSOR**
5. Name of your agent *(if you have one)*
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Patents form 1

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**DESCRIPTION****PHOTO SENSOR**

5           This invention relates to photo sensors and the manufacture thereof, and particularly, but not exclusively, those employed in the pixel circuits of active matrix electroluminescent displays which comprise thin film transistors having a polycrystalline silicon channel.

10           Active matrix electroluminescent display devices which employ light emitting display elements are well known. The display elements may comprise organic thin film electroluminescent elements, for example using polymer materials, or else light emitting diodes (LEDs) using traditional III-V semiconductor compounds. Recent developments in organic  
15   electroluminescent materials, particularly polymer materials, have demonstrated their ability to be used practically for video display devices. These materials typically comprise one or more layers of a semiconducting conjugated polymer sandwiched between a pair of electrodes, one of which is transparent and the other of which is of a material suitable for injecting holes or  
20   electrons into the polymer layer.

          An active matrix electroluminescent display device generally comprises a row and column array of pixels. The supply of current to the display element of each pixel is controlled by a respective pixel circuit which typically comprises thin film transistors (TFTs). At least one of the TFTs, often referred  
25   to as the drive transistor, in each pixel circuit is employed to regulate the flow of current through the display element. It is important that the electrical characteristics of the drive transistor are stable throughout the operation of the display. TFTs having an amorphous silicon channel are known to suffer from problems such as threshold voltage drift when used to control continuous  
30   currents. For this reason, TFTs having a polycrystalline silicon (polysilicon) channel are favoured over amorphous silicon TFTs for use as the drive

transistor. However, structural differences in polysilicon channels from one TFT to another can lead to differences in their electrical characteristics.

In addition to the problems associated with non-uniformity of polysilicon TFT characteristics, electroluminescent display elements are known to suffer from aging effects. For example, "burn-in" is caused by the prolonged operation of particular pixels in the array and results in non-uniform output intensities between pixels despite being driven with the same signals.

In order to correct for non-uniformities in the pixel outputs it is known to incorporate a photo sensor in each of the individual pixel circuits. Each photo sensor serves to measure the light output from its respective pixel and is connected in the pixel circuit in such a way as to compensate for the non-uniformity problems described above. Examples of such are known from WO-01/20591, which contents are incorporated herein by way of reference.

Photo sensors formed of amorphous silicon are preferred over those formed of polysilicon because the optical absorption of amorphous silicon is several orders of magnitude higher over parts of the visible light range. An amorphous silicon photo sensor therefore provides a much higher signal to noise ratio in the associated correction circuitry.

For the reasons described above, each pixel circuit in a high quality active matrix electroluminescent display device preferably comprises polysilicon TFTs and amorphous silicon photo sensors. Figure 1 shows a sectional view of part of a pixel circuit having such a combination in a known arrangement. A polysilicon TFT 10 and an amorphous silicon photo sensor 12 are disposed on a substrate 14.

The TFT 10 shown is a top-gate type having a polysilicon channel 15 with adjacent doped polysilicon source and drain regions, 16 and 17. These regions may be doped either n-type or p-type. However, both n-type and p-type TFTs are often formed on the same substrate. A gate insulating layer 18 separates the channel 15 from a metallic gate 20.

When patterning the gate 20, a photo sensor contact 22 is also defined using the same metal layer. An n-i-p stack is then formed on the photo sensor contact 22 to provide a vertical amorphous silicon photo sensor 12. This stack

comprises a layer of n-type amorphous silicon 24, a thicker layer of intrinsic silicon 25, and a layer of p-type amorphous silicon 26. These layers are deposited sequentially and then patterned into an island.

5 A top contact 28 is then formed of a transparent conductive material such as indium tin oxide (ITO) over the amorphous silicon stack. This allows light 100 from the overlying electroluminescent display element (not shown) to pass to the intrinsic silicon of the photo sensor.

One significant problem associated with the formation of the n-i-p stack is the difficulty in doping the p-type layer 26 during the deposition process. The 10 doping is commonly carried out by gas phase doping. Dedicated equipment and gases are required in order to perform gas phase doping to avoid the undesirable contamination of the deposition chamber. Also, the gases 15 required,  $B_2H_6$  for example, are classed as particularly hazardous to work with and there is increasing pressure to remove such gases from the workplace 20 due to health and safety concerns. This presents a significant barrier to large-scale manufacture of active matrix electroluminescent display devices having amorphous silicon photo sensors with polysilicon TFTs.

20 The present invention provides methods of manufacturing photo sensors that offer or permit improvements over known methods. Various novel concepts, inventive concepts and specific embodiments are disclosed herein, particularly but not exclusively with reference to the accompanying drawings.

In accordance with one aspect of the present invention there is provided a method of manufacturing photo sensors in pixel circuits of an active matrix 25 electroluminescent display which comprise thin film transistors having a polycrystalline silicon channel, the method comprising one or more novel process steps as recited in the following description of embodiments of the invention.

30 These and other features and advantages of the present invention will become apparent from reading of the following description of preferred embodiments, given by way of example only, and with reference to the accompanying drawings, in which:-

Figure 1 is a sectional view through part of a pixel circuit of an active matrix electroluminescent display device having a known arrangement of circuit components;

Figure 2 is a sectional view through part of a pixel circuit having a photo sensor according to a first embodiment of the invention; and,

Figures 3 and 4 are sectional views through part of a pixel circuit having a photo sensor according to a second embodiment of the invention at different stages of fabrication.

The same reference numerals are used throughout the Figures to denote the same, or similar, parts. It should be understood that the Figures are merely schematic and are not drawn to scale. In particular, certain dimensions have been exaggerated whilst others have been reduced.

It has been recognised by the inventor that the doped source and drain contact regions of the polysilicon TFTs can be employed to form at least one of the doped regions in an amorphous silicon photo sensor. By sharing a doped region in this way, the requirement to provide a separate doped region for the photo sensor is removed. Example structures in which at least one doped region is shared between a TFT and a photo sensor will now be described.

Figure 2 shows two TFTs, 10a and 10b, disposed on a substrate 14 and each having a polysilicon channel region, 15a and 15b. The first TFT 10a has n-type doped source and drain regions, 16a and 17a. The second transistor 10b has p-type doped source and drain regions. The respective metallic source and drain contacts have not been shown here for simplicity.

The polysilicon island defining the channel, source and drain regions of each TFT is formed in a known manner. For example, a layer of amorphous silicon is deposited on the substrate and source and drain regions are then selectively doped by ion implantation. Following this the amorphous silicon layer is patterned into islands and then crystallised by laser annealing for example. It will be appreciated by the skilled person that there are variations on this method for forming the islands. For example, it is known to crystallise the silicon layer before the patterning step.

The active matrix array typically comprises many thousands of TFTs disposed on the substrate. However, only two are shown in Figure 2 for simplicity. In accordance with a first embodiment of the invention, the n-type doped drain region 17a of one TFT 10a and the p-type doped source region 16b of an adjacent TFT are used to define also the doped contacts for an amorphous silicon photo sensor 12. Therefore, the separate doped regions for the photo sensors of Figure 1 are not required. It will be appreciated that the adjacent TFTs employed for this purpose are of opposite conductivity types, i.e. one n-type and one p-type.

To provide the intrinsic region of the photo sensor 12, a layer of intrinsic amorphous silicon is deposited over the substrate and patterned into individual islands positioned between a respective pair of adjacent TFTs. Each island contacts an n-type doped region of one TFT and a p-type doped region of the other.

Therefore, n-i-p diodes which can serve as photo sensors are defined on the substrate without the need for dedicated gas phase doping equipment. Advantageously, this method provides a simple, and therefore cheap, route to manufacturing active matrix electroluminescent display devices incorporating photo sensors.

The resulting arrangement of the method according to the first embodiment, as shown in figure 2, comprises a lateral n-i-p diode 12 which provides certain advantages over the vertical arrangement of Figure 1 for example. Firstly, the vertical arrangement requires a relatively thick amorphous silicon layer, 0.25 - 1.50 $\mu$ m for example, in order to ensure that the reverse leakage current is of a low enough value to allow effective operation of the device. Providing a layer having this thickness is relatively difficult and time consuming. In contrast, the distance between the doped contact regions of the photo sensor in Figure 2 is equal to the gap between adjacent TFTs. In this case, the reverse leakage current can be maintained at an acceptably low level by using a thinner intrinsic layer. Advantageously, this intrinsic layer can be formed simply by deposition and patterning.

A gate insulator layer 18, for example of  $\text{SiO}_2$ , is then deposited over the substrate. A metal layer, of aluminium for example, is then deposited over the substrate and patterned to define a gate 20a, 20b, for each TFT. A transparent conductive gate 30 is then formed in a similar manner over the intrinsic region of the n-i-p diode. This serves, during operation, to apply a voltage to the diode so that it can control, to some extent, the conductivity between the doped contacts. For example, charge from an adjacent insulator can accumulate in the channel and affect the off-current. A biasing voltage applied to the gate 30 can advantageously minimise the off-current. The transparency of the gate is required to enable the light 100 from the display element to pass therethrough.

It will be appreciated that the gate 30 above the photo sensor is an optional feature which can be omitted if required without deviating from the advantages provided by the shared doped regions.

With reference to Figures 3 and 4, a vertical n-i-p stack can be provided by using a doped region of one polysilicon TFT for the n-type region. The p-type region is formed by depositing aluminium on the intrinsic amorphous silicon island and annealing so that the aluminium diffuses into the amorphous silicon thereby doping it p-type. The aluminium can then be patterned to reveal the underlying p-type region. Fabrication of a photo sensor according to this second embodiment will now be described.

In a similar manner to the above-described embodiment, a polysilicon island is formed on a substrate 14 by deposition, patterning and annealing of an amorphous silicon layer. n-type source and drain regions, 16, 17, are defined by ion implantation prior to annealing the amorphous silicon. A layer of intrinsic amorphous silicon is then deposited over the substrate and patterned to define an island 25' disposed on part of the n-type drain region 17, as shown in Figure 3. This island provides the main body of the vertical photo sensor.

An insulating layer is then deposited over the substrate to provide the gate insulating layer 18. A metallic gate electrode 20 is then formed over the channel 15. A passivation layer 35 is then deposited over the entire substrate.

The top surface of the intrinsic amorphous silicon island is then exposed by etching away part of the passivation layer 35 and the gate insulating layer 18. Also, vias are formed to allow contact with the underlying source and drain regions 16,17, of the TFT.

5        A layer of aluminium is then deposited and patterned to define source and drain contacts, 36,37, and a top photo sensor contact 40. It will be appreciated that an aluminium alloy can instead be used for this purpose. The top photo sensor contact 40 is then annealed by heating to 200°C for 20 minutes for example. This annealing process causes aluminium ions to diffuse  
10        Into the underlying intrinsic island 25', doping a region p-type. In addition, the annealing crystallises at least a portion of the doped p-type region which enhances the doping effect.

With reference to Figure 4, part of the top surface of the p-type region 26 is thereafter exposed by etching away part of the aluminium top photo  
15        sensor contact 40. This allows exposure of the n-i-p stack to light 100 emitted from the overlying display element.

From this method, a highly effective p-type contact 26 can be formed without the use of gas phase dopants.

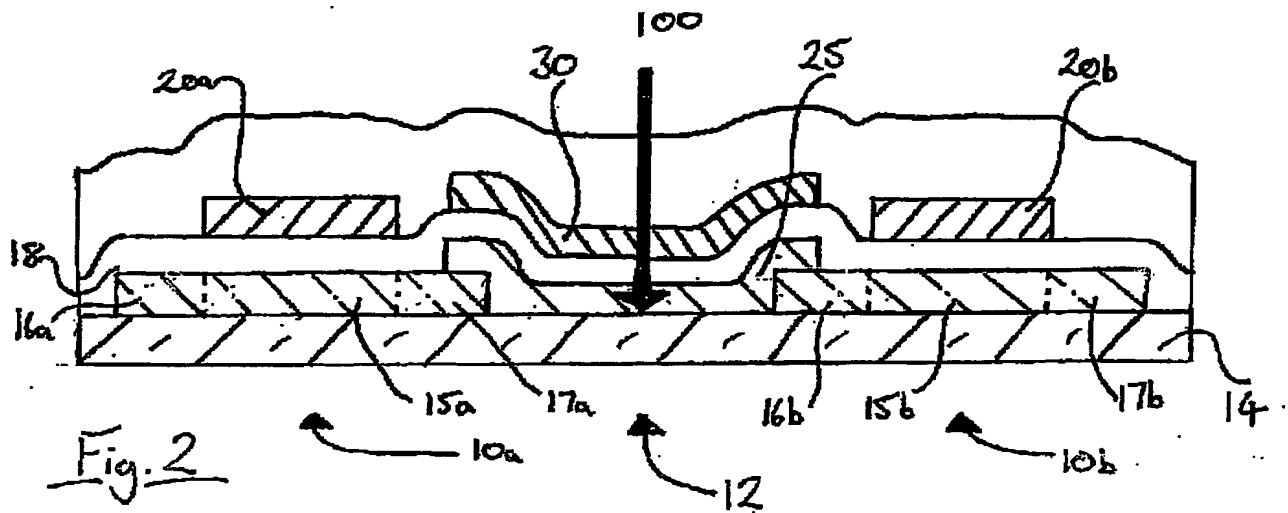
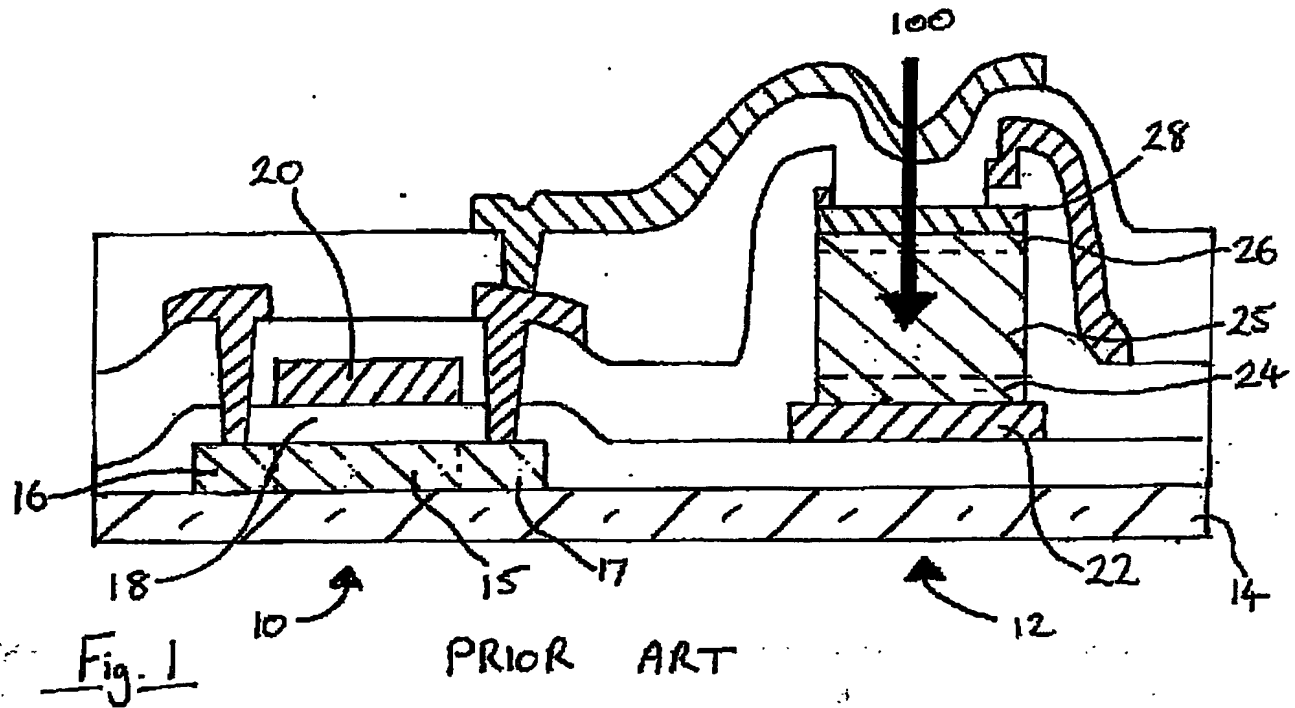
From the present disclosure, many other modifications and variations  
20        will be apparent to persons skilled in the art. Such modifications and variations may involve other features which are already known in the art and which may be used instead of or in addition to features already disclosed herein. It should be understood that the scope of the disclosure of the present application includes any and every novel feature or combination of features disclosed  
25        herein either explicitly or implicitly and together with all such modifications and variations, whether or not relating to the main inventive concepts disclosed herein and whether or not it mitigates any or all of the same technical problems as the main inventive concepts. The applicants hereby give notice that patent claims may be formulated to such features and/or combinations of such  
30        features during prosecution of the present application or of any further application derived or claiming priority therefrom.

**CLAIMS**

1. A photo sensor for use in an active matrix electroluminescent display device, the photo sensor having one or more novel elements or combinations  
5 of elements as recited in the description of embodiments of the invention.

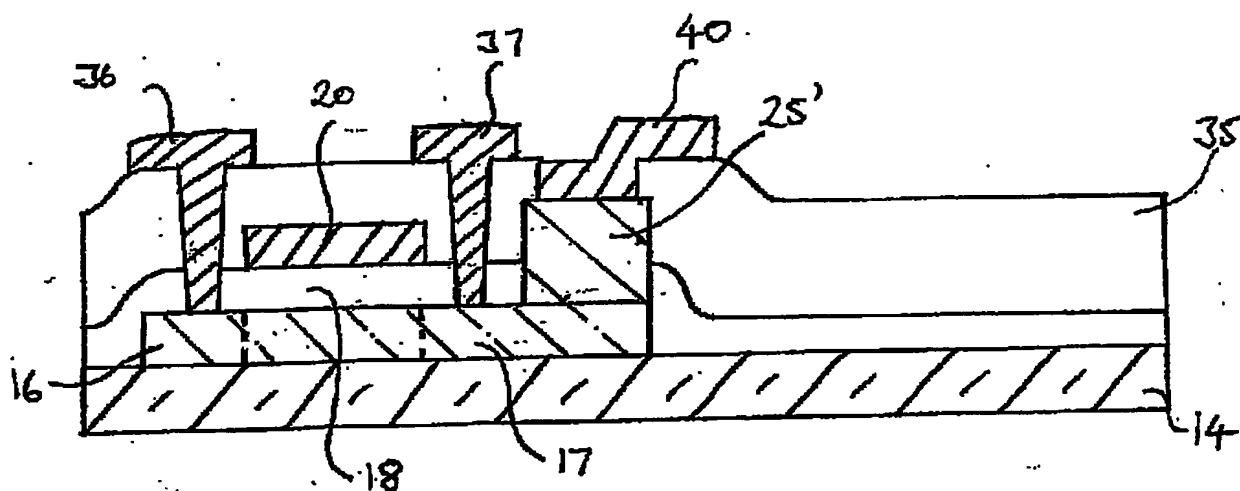
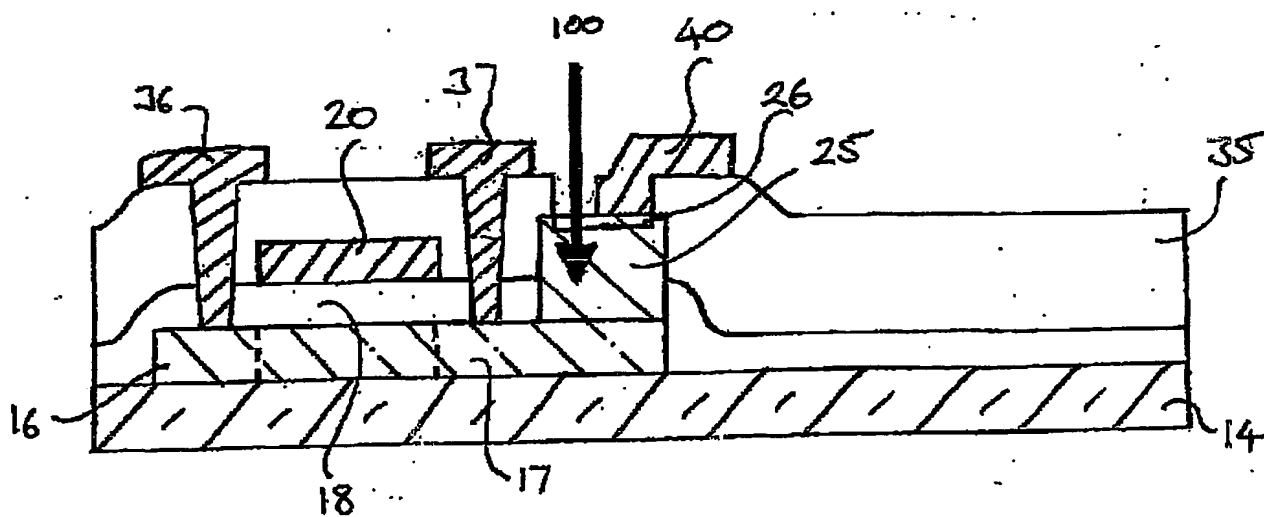
2. A method of manufacturing photo sensors for use in pixel circuits of an active matrix electroluminescent display which comprise thin film transistors having a polycrystalline silicon channel, the method comprising one or more  
10 novel process steps as recited in the description of embodiments of the invention.

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Fig. 3Fig. 4

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